Sparking Conversations About Graduate Programs in Geoscience Education Research*

Karen S. McNeal[1,a] and Heather L. Petcovic[2]

ABSTRACT

The calls for a college-educated science and technology workforce, as well as a scientifically literate citizenry, have led to a demand for higher education faculty prepared in discipline-based education research (DBER). These faculty members conduct research on teaching and learning in the context of a specific discipline, including the geosciences. Historically, faculty have become active in geoscience education research (GER) after completing a graduate degree in a "traditional" geoscience discipline such as geomorphology, paleontology, or structural geology. Increasing demand for GER faculty has led to the growth of graduate programs specializing in GER. We explore the current state of GER graduate preparation in the United States and the issues moving forward in establishing and advancing GER graduate programs. We hope to spark discussion in the GER community about what GER graduate preparation entails, as programs grow and proliferate, to assist the community in being intentional in the preparation of future professionals. We make key recommendations for the GER community, including: (1) hold community-wide discussions about GER graduate training, (2) investigate methodological training as a shared graduate training experience in GER, (3) embed authentic teaching and research opportunities in graduate programs that mirror a student's planned career trajectory and assist them in becoming reflective teachers, (4) encourage GER faculty to continue to inform their colleagues and administrators about GER and what it is (and is not), and (5) look beyond GER to how other DBER fields design and implement graduate programs. © *2017 National Association of Geoscience Teachers*. [DOI: 10.5408/17-254.1]

Key words: graduate preparation, geoscience education research

INTRODUCTION

For at least the past decade, federal agencies have warned of a coming shortage of science and technology workers that will reduce the United States' competitiveness in the global economy (e.g., NRC, 2007; PCAST, 2012). At the same time, solutions to societal problems such as limited natural resources, anthropogenic climate change, and loss of biodiversity will require a scientifically literate citizenry (Kober, 2014; Snow and Dibner, 2016). In order to solve these problems and succeed in today's workforce, university science and technology graduates are expected to possess critical thinking skills, have the ability to work collaboratively, and apply learned knowledge and skills to real-world problems that they are committed to solving (NSB, 2015). Higher education departments are called upon to address all of these issues, including increasing the number and quality of science and technology workers, ensuring that citizens have a sound scientific basis for making decisions, and teaching critical thinking and other professional skills. However, many students, especially women and students of color, leave science and technology fields during their undergraduate years, in part due to poor teaching and perceptions of science as unwelcoming (Seymour and Hewitt, 1997).

In response to these problems and demands, as well as in response to shifts in federal funding priorities supporting undergraduate learning, the field of discipline-based education research (DBER) has emerged (NRC, 2012). DBER "investigates learning and teaching in a discipline from a perspective that reflects the discipline's priorities, worldview, knowledge, and practices. It is informed by and complementary to research on learning and cognition" (NRC, 2012, I-2). DBER scholarship aims to advance knowledge of teaching and learning through theory generation and empirical testing or questioning (NRC, 2012; Dolan et al., 2017; Henderson et al., 2017; NAGT, 2017b). Developing in parallel to but somewhat isolated from DBER, the field of scholarship of teaching and learning (SoTL) aims to create and disseminate effective educational innovations and support faculty in adopting evidence-based teaching practices (NRC, 2012; Dolan et al., 2017). Although not strictly confined to higher education, most DBER and SoTL scholarship focuses on issues of teaching and learning at the undergraduate through professional levels. The geoscience education community has deliberately included both DBER and SoTL under the term geoscience education research (GER) (Shipley et al., this volume). However, for this paper, we focus on the DBER end of GER, since it represents the structure of most graduate programs and the research agendas of the faculty who direct graduate student theses and dissertations.

DBER faculty are hired not only to conduct research, but often to facilitate postsecondary teaching that incorporates reformed, research-based practices, and/or to enhance the preparation of K–12 teachers (NRC, 2012). An increase in hiring of GER faculty has paralleled the growth in DBER

Received 20 February 2017; revised 22 June 2017; accepted 27 June 2017; published online 16 November 2017.

[1]Department of Geosciences, Auburn University, 2050 Beard Eaves Coliseum, Auburn, Alabama 36849, USA

[2]Department of Geosciences and the Mallinson Institute for Science Education, Western Michigan University, 1903 West Michigan Avenue, Kalamazoo, Michigan 49008, USA

[a]Author to whom correspondence should be addressed. Electronic mail: karen.mcneal@auburn.edu. Tel.: 334-844-4806.

*Commentary for *Journal of Geoscience Education* Special Issue on Synthesizing Results and Defining Future Directions of Geoscience Education Research.

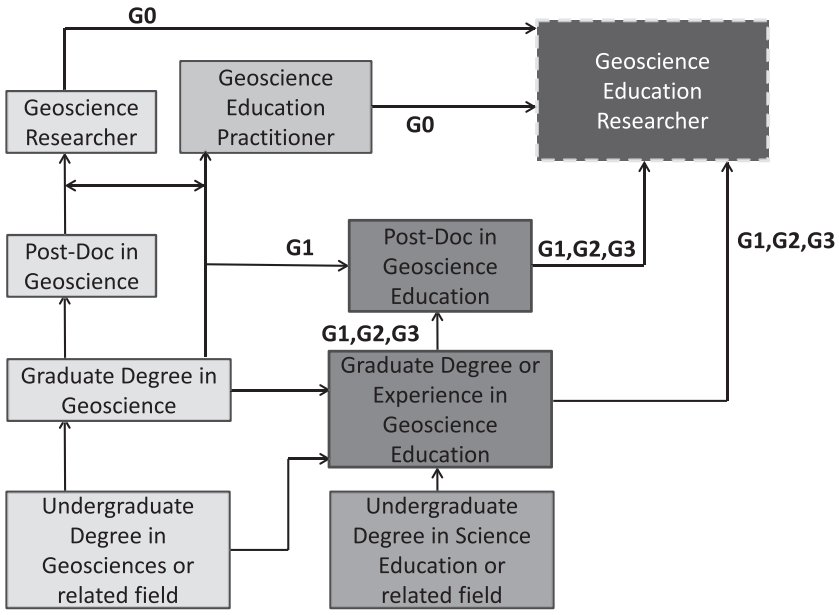

FIGURE 1: Pathways to the development of a GER researcher. G0–G3 are defined as generations 0, 1, 2, and 3; however, they can exist simultaneously and may be considered subspecies with researchers entering GER from any pathway at any given time. Figure modified from NAGT (2017a).

generally. In these positions, GER faculty may be expected to build an externally funded research program that includes the preparation of graduate students in GER. However, baseline preparation of aspiring GER professionals has not been established, despite calls for community-wide discussion (Feig, 2013).

As two GER faculty, we here describe our experiences of preparing GER graduate students in two different pathways: (1) one author's experience in a collaborative science education program in which GER is one of several DBER strands, and (2) one author's experience in a disciplinary geoscience department housed within a college of science. We also discuss the history of GER faculty preparation and prospective careers for GER graduates, as well as questions that departments and other administrative units might consider when establishing a new GER program and hiring associated faculty.

DEVELOPMENT OF GER FACULTY

There are many pathways to becoming a GER researcher (NAGT, 2017a). An individual's pathway to GER is primarily grounded either in geoscience or in education (e.g., K–12 teacher preparation) and facilitated through graduate education and/or postdoctoral or professional experience (Fig. 1). Historically, faculty have been limited in their preparation to conduct geoscience education research and often had traditional training in the geosciences before beginning research in GER. Before formal GER graduate programs were established, faculty most commonly entered GER through their own motivation to improve their teaching practices or to engage in geoscience outreach efforts. Tenured faculty in geoscience departments typically learned methods of geoscience education research through professional development, by working with experienced mentors, and/or on their own through trial and error. This group of pioneering researchers is commonly called generation zero or G0, and they were instrumental in founding organizations such as the National Association of Geoscience Teachers (NAGT) and the *Journal of Geoscience Education*. In one sense, G0 is an historical term, as this was the typical pathway of the founders of GER. Despite the diversity of pathways now available to enter GER, the G0 path continues as a viable route for many individuals who discover GER later in their careers (Fig. 1).

Once GER had a foothold as a field of study in the geosciences, a second generation of GER scholars arose. G1 scholars found their ways to GER in a variety of ways: as students of G0 faculty, as traditional geoscientists who discovered a deep interest in teaching and learning, or as science educators who discovered the geosciences. The major difference is that G1 scholars typically entered the field much earlier in their careers than G0 faculty, often as graduate students, postdoctoral researchers, or early career faculty. As graduate students, some G1 practitioners gained formal GER training through completing blended dissertations that addressed both traditional disciplinary geoscience topics as well as GER. Other G1 practitioners earned their doctorates in science education and then focused their research programs on issues of teaching and learning in the geosciences. Still others received formal training in science education as graduate students through programs funded by the National Science Foundation (NSF) such as GK-12 (graduate STEM fellows in K–12, where STEM represents science, technology, engineering, and mathematics). A further route to GER was through postdoctoral experience such as a NSF-funded postdoctoral fellowship in science, mathematics, engineering, and technology education (PFSMETE), or through the Carl Wieman Science Education Initiative. Many of these G1 individuals went to tenure-track, instructor, and research positions at a range of institutions (including two-year colleges, teaching-focused institutions, and research-intensive institutions), where they engaged in GER prior to the acquisition of tenure. As with

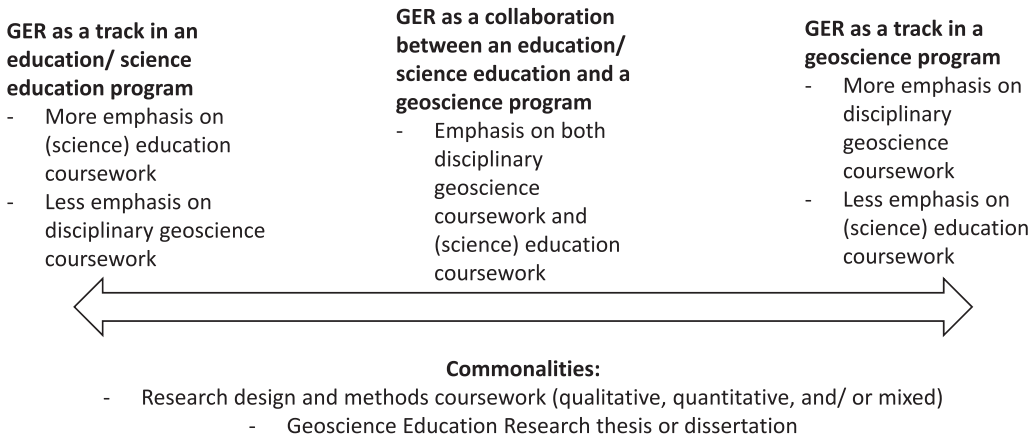

FIGURE 2: A continuum of approaches to graduate preparation in geoscience education research.

G0, G1 remains a viable pathway to GER for many individuals (Fig. 1).

Both authors self-identify as G1 faculty. One (K.S.M.) completed a blended GER and geoscience dissertation and was a graduate assistant in a NSF Teaching and Learning Center and secured a NSF GK-12 fellowship during her PhD studies. She earned tenure in her first faculty position with both traditional disciplinary research and GER and then went on to resecure tenure as a GER faculty member at a different institution. The other author (H.L.P.) completed a traditional geoscience dissertation and a NSF GK-12 fellowship, entered GER as a tenure-track faculty member, and successfully earned tenure with her research focus in GER.

G0 and G1 faculty established the earliest formal graduate preparation programs in GER, giving rise to G2, the first generation of GER practitioners earning graduate degrees in GER. At this point in time, many G2s have established graduate programs of their own and are preparing G3 students.

We appreciate that individuals will continue to join GER at many stages of their careers and through any of the pathways identified in Fig. 1. We would like to note that the G0–G3 categorization is not necessarily a linear progression of the evolution of GER, but rather it can be thought of as an ecological framework in which "subspecies" G0–G3 researchers can coexist, represent viable pathways of entry to GER, and be equally beneficial to the success of the system (in this case, the GER community). However, we focus this paper on the formal preparation of the next generation of G2 and G3 researchers who will have explicit GER training in their graduate education and experience mentorship directly from GER faculty. Both authors have mentored G2 GER students who have since entered postdoctoral and faculty positions.

APPROACHES TO GRADUATE GER PREPARATION

The variety of ways to approach graduate student preparation for GER reflects both where GER faculty and thus their graduate programs are housed, and the interdisciplinary nature of GER itself. GER practitioners have deep knowledge of one or more content areas within the geosciences, knowledge of one or more content areas within science education (which in turn overlaps with cognitive science and educational psychology), and facility with social science research methods. Furthermore, many GER faculty are expected to contribute to the preparation and/or professional development of elementary or secondary teachers. In most universities, there is a divide between disciplinary science programs, typically housed in colleges of science, and education or science education programs, typically housed in colleges of education. So where do GER faculty and their GER graduate preparation programs belong?

We see three basic structures to housing GER graduate programs and affiliated faculty, each with several potential variations, which can be positioned on a continuum from programs dominated by disciplinary geoscience to those dominated by science education (Fig. 2). Some GER programs are housed fully in a geosciences unit, which itself may be limited to geology/geosciences, or which may be part of a larger natural science, earth, space, ocean, environmental, engineering, and/or atmospheric science unit. The GER faculty may have teaching and service responsibilities solely within the geosciences unit, or they may have their duties split between the geoscience and education units. GER programs housed entirely within geoscience departments tend to emphasize that graduate students enroll in geoscience content coursework at the expense of taking science education coursework. In this arrangement, essentially GER is one of many subdisciplines within the geosciences. The first author has experience in this organizational approach.

At the other end of the spectrum, the GER graduate program may be housed fully within an education unit (a science education department, or a department housed within a college of education; Fig. 2). GER faculty in this program structure likely have their primary teaching and service responsibilities related to the preparation of elementary and secondary teachers. Programs housed in an education or science education unit by their nature tend to emphasize that graduate students take science education coursework at the expense of disciplinary geoscience content coursework. Neither author has experience with this type of structural organization, though a few programs structured in this manner currently exist (Libarkin, 2017).

Positioned between these end members, some GER programs represent collaborations between geoscience units

and science education units (Fig. 2). This could be a formal arrangement for the GER faculty such as a joint appointment between two units, or a single appointment and an affiliation with an educational research or teaching and learning center. The GER graduate program could also be a joint endeavor between the science education and the geosciences units. This type of program may include coursework in both science education and the geosciences. The second author's GER graduate program is organized in this manner; she holds a joint appointment in both the geosciences department and the science education program, and GER is one of five DBER doctoral tracks (biology education, chemistry education, geoscience education, physical geography education, and physics education), each of which is administered through the science education program but was jointly developed with each science department.

A common factor in all GER preparation programs is grounding in research methods appropriate to the learning and social sciences. Coursework in qualitative and quantitative, plus perhaps mixed, research design and methods is integral to preparing students for thesis or dissertation work. Second, across this continuum, there is an expectation that the thesis or dissertation research will be in GER, either entirely GER or a blend of GER and disciplinary geoscience research. In particular, dissertations composed of multiple papers lend themselves to the blended approach.

DISCUSSION POINTS FOR THE GER COMMUNITY

As we consider how GER programs and faculty are structured and the array of GER preparation approaches, we as a GER community need to consider several lines of questions moving forward.

Questions About GER Graduate Preparation Programs

Where the GER graduate program is housed (Fig. 1) has important ramifications for the type of degree conferred and thus the potential career paths for students. For instance, will the degree earned indicate a department of geosciences or a department of education? How might the name of the student's graduate program impact the student's ability to secure a position? What credentialing does the hiring entity value? In other words, does a degree from an education unit help or hinder a student in a faculty search in a geoscience department, and is a geoscience degree acceptable for an education faculty position? What is the culture of the degree-granting department, and how much interaction is there between the college of science and the college of education? These are all questions that the GER community needs to consider as well as to share with prospective students as they investigate and visit potential GER graduate programs.

Next, what should GER graduate preparation look like? Is there an "ideal" point on the spectrum in Fig. 2 for GER graduate programs? Do all GER graduate students need the same preparation? In the case of traditional disciplinary geology programs, for instance, a common course sequence ensures that a student has been "trained" in the discipline. Given that GER is a graduate-level program, should we consider a common structure, or should we allow the research area and the committee of the student to determine the coursework needed, as we do with many other areas of graduate geoscience preparation?

We next raise questions about the content and requirements of GER graduate programs themselves. First, is there an accepted "canon" of GER literature that all GER practitioners should know? If so, how do we agree upon this body of literature? How do we ensure that all GER graduate students are familiar with the core work of our field? In more established fields of geosciences (and education), there is certainly a core body of literature that the field has deemed "classic" reading. Perhaps GER is reaching the point where seminal works can be recognized?

Most graduate programs in the geosciences allow graduate students to submit a paper (typically for a master's degree) or a series of related papers (typically for a doctoral degree) in lieu of a single, comprehensive thesis or dissertation. Should we encourage this approach for GER graduate students? Should we include a publication requirement in a master's or doctoral program? Should we include a requirement for the student to present work at a conference or to submit a grant proposal? If we anticipate that many GER program graduates will attain faculty positions, then experience with presentation and publication, as well as grant writing, is critical.

One factor to bear in mind is the diverse entry points into a GER program. Some students come to GER with undergraduate and/or graduate degrees in the geosciences and an interest in teaching and learning. Some have degrees and/or experience (often years to decades of experience) in K–12 or community college teaching in the geosciences before coming to GER. Some have combined disciplinary geoscience and teaching backgrounds. In both authors' experience, however, we find that nearly all students starting in GER lack preparation in both qualitative and quantitative education research methods and lack grounding in the epistomological commitments and theories that underlie various research traditions in the social science. Therefore, coursework in methods theory could easily be a common starting point for thinking about basic graduate expectations.

Both authors also find that incoming GER students tend to have limited teaching experience at the college level, and some lack any formal teacher preparation. Furthermore, few have experience or training in curriculum development. Yet, many GER program graduates will pursue teaching-focused faculty positions, or other instructional positions requiring facility with instructional design. Should we expect all GER graduate students to become reflective teachers and to gain experience in development and assessing curricula? If so, how do we provide support, mentoring, and continued professional development that enable GER graduate students to become competent instructors and instructional designers?

Questions About Careers in GER

In order to ensure that our GER graduate students develop the necessary skills and habits of mind that enable them to pursue their desired careers, we first need to determine what types of career opportunities are available. We typically think first of academic positions; indeed, the past decade has seen a steady growth in DBER positions, ranging from research-intensive to teaching-intensive tenure-track and non-tenure-track positions, at both four-year and community college institutions. However, we should

TABLE I: Potential list of careers for GER specialists.[1]

Potential GER Careers	Setting	Degree Needed	Description
Tenure track faculty (e.g., assistant professor)	Academia—two-year and four-year institutions	PhD	Includes teaching, research, and service responsibilities; may vary in distribution depending on institution type.
Tenure track or non-tenure-track faculty—teaching specialist (e.g., teaching professor)	Academia—two-year and four-year institutions	PhD[2]	Includes only teaching responsibilities; some service responsibilities may also be included.
Non-tenure-track faculty—teaching specialist (e.g., instructor/lecturer)		MS or PhD[2]	
Non-tenure-track position—research specialist (e.g., research assistant professor)	Academia—typically four-year institutions	PhD[2]	Includes only research responsibilities, usually "soft" funded.
Administration (e.g., director of teaching and learning center, assistant dean of inclusion and diversity, director of educational programs at a museum, program officers, etc.)	Academia; federal/state agency	PhD	Some experience in the organization may be required. Supervises workers/programs, develops larger-scale/system-wide programs, handles budgets, serves organization and its constituencies, etc.
	Informal education; industry; federal/state agency	MS or PhD	
Education and outreach staff (e.g., education programmer, program coordinator, education specialist, trainer, curriculum developer, outreach staff)	Informal education; nonprofit organizations, academia; state/federal agencies;	MS	Development and implementation of education programs or curricula; may include training staff in "ways of knowing" within the institution or organization.
	Industry (often oil and gas)	MS or PhD[2]	Develops and delivers training materials and workshops for industry employees and/or manages resources to/oversees company-supported STEM[1] outreach programs.
	Academia—typically four-year institutions	MS or PhD[2]	Includes activities that are directed toward the education and interests of the local/state-wide community that the institution serves.
Program evaluator; assessment specialist (e.g., project manager or research associate)	Academia; consulting/industry	MS or PhD[2]	Evaluates and reports on program successes and areas of needed development.
Teacher (e.g., science teacher, science curriculum coordinator)	K–12	BS or MA or MS	Often teaches in a science field; may require teaching certification.

[1]GER = geoscience education research; STEM = science, technology, engineering, and mathematics.
[2]EdD may be an acceptable degree in some cases.

also think more broadly about the qualifications and skills that students who graduate with a GER specialization may possess. For instance, positions in teaching and learning centers providing professional development for faculty at a variety of universities are potential opportunities. GER program graduates could also go into evaluation; many grant-funded geoscience education and outreach projects are in need of external evaluators who have a background in GER. Other types of positions could include leadership at state or national funding agencies, outreach and informal education initiatives, and secondary school opportunities (especially for those students that have K–12 teaching credentials). In addition, GER graduates could work for federal agencies or the private sector as education and professional development leaders. Also, informal education positions in an array of sectors (private and public) could be potential options for employment. See Table I for a list of possible career opportunities for GER graduates.

We therefore pose a critical question to the GER community: Are we preparing our students to think reflectively about their careers, and are they getting the necessary experiences in graduate school to pursue post-graduation opportunities? Given the breadth of potential GER careers, faculty mentors, especially those in disciplinary geoscience programs, may not be aware of GER career paths and opportunities. How can we ensure that faculty mentors provide the support needed for G2 and G3 students in GER to pursue the full array of career possibilities? As a possible response, should we include mentors both inside and outside of academia on student research committees? At a higher level, are we, as GER practitioners, thinking reflectively about our own careers, given the huge diversity of situations in which we may find ourselves? With the uncertainties that GER faculty may be experiencing within their own departments (e.g., tenure, promotion, funding, etc.), can careful planning and preparation of GER graduate students even occur?

Questions for Departments Hiring GER Faculty to Develop and Sustain a Graduate Program

To develop and sustain a GER graduate program, an institution must hire faculty with expertise in this area. As more GER graduates enter the job market and academic positions, they must be aware of the institutional landscape and the potential challenges to success as a GER faculty member. Simultaneously, as more institutions hire GER faculty and begin GER graduate programs, we raise questions that faculty, department heads, and senior administrators should consider. For instance, do faculty colleagues and administrators recognize the value that GER researchers, their students, and GER graduate programs bring to the department and institution? Obviously, a GER graduate program increases capacity for obtaining external funding and generating new knowledge. However, a GER program may also add expertise in teaching and learning at the department and institution, with trained, passionate, and motivated faculty and graduate students. A GER program could enhance recruitment of undergraduate students to the geosciences or increase the number of K–12 teachers qualified to teach Earth Science. GER faculty and graduate students could reach out to untapped undergraduate and graduate student interest, potentially recruiting and retaining students of greater gender, racial, and research diversity than currently housed in the department.

Once GER faculty are hired, has the department carefully thought about tenure and promotion? In doing so, have they taken the approach that they must adopt "different" tenure and promotion expectations for the GER practitioner? Rather, have they embraced, accepted, and valued the new knowledge that a GER faculty member will bring to the institution without needing a different criterion to succeed? Have they "done their homework" to understand the culture and norms of GER in terms of publishing and external funding? Do they recognize the scholarly literature in which GER is embedded? Moreover, has the department inquired about the publication expectations for faculty in related areas (e.g., educational psychology, science education, cognitive science) as a reference for the type of products valued in this interdisciplinary field? Do faculty colleagues and department heads even recognize GER as a legitimate field of scholarship, or do they view GER as simply good teaching? Will the graduate students and the faculty in the GER program be treated as equals or as second-class citizens? Additionally, is the department being consistent with their expectations of both GER and traditional faculty (and their students), in a geoscience department or in an education program, while also valuing the unique differences between the two? Setting up a GER graduate program requires a substantial investment of time and resources; having clear alignment between departmental expectations and the individual GER faculty member's research program is critical to long-term success of a GER graduate program.

RECOMMENDATIONS AND CONCLUSIONS

Almost six years ago, the authors of the NRC (2012) report recognized the need for the DBER community to start considering best practices for the education and training of DBER graduate students. The NRC report (2012, 34) states, "Graduate education in DBER is itself ripe for further study and exploration. As DBER fields mature, a growing number of researchers have been trained in DBER graduate programs and are now in academic positions. Now is the time to ask questions, not only about the outcomes of a DBER graduate education (job placement, research productivity/contributions, etc.), but also about best practices for educating graduate students in DBER." Given this NRC (2012) recommendation, as well as the questions raised herein, further community-level discussion of graduate programming in GER is warranted. We suggest continuing this conversation through workshops or roundtable discussions at venues such as the Earth Educators Rendezvous. A focused conference or working group to deeply explore these questions may be necessary. We also suggest that research to understand current educational practices being used in GER graduate programs (and the larger DBER graduate programs), graduate student needs and career trajectories, and faculty perspectives on GER training priorities is needed.

As a baseline to graduate training, we recommend that GER graduate programs require a series of both qualitative and quantitative research theory design and methods (including statistics) courses drawn from the social sciences. Strong methodological foundations among our GER graduates will make the work portable beyond GER and build knowledge across domains (e.g., education, cognitive science, DBER, education psychology). This recommendation echoes that of Feig (2013, 316), who recommended that "graduate-level courses in educational research design, parametric and nonparametric statistics, and qualitative inquiry [in GER programs]" be a part of GER student preparation. Additionally, Feig (2013) suggested establishing apprenticeships or internships that could increase student skill development for their anticipated career. We also suggest reaching out to nonacademic GER community members and inviting them to serve on graduate student thesis and dissertation committees as a mechanism to assist students in conducting appropriate research for their field of interest and gain mentorship outside of academia.

We further recommend that GER programs include advanced preparation in both science education and geoscience content, though what exactly this preparation would entail is open for discussion. In an era of increased scrutiny for accreditation in higher education, this may assure that GER faculty are qualified to teach disciplinary geoscience and/or education undergraduate- and graduate-level courses. Furthermore, we advocate for GER graduates to demonstrate mastery of teaching and instructional design at a level consistent with their desired career path in order to support their development as reflective teachers. For example, programs could require K–12 experience, or college-level teaching assistant (or instructor/lecturer) experience coupled with professional development. Professional development could take place in a mentored teaching experience, in a formal course (akin to a K–12 methods or curriculum design course), or through a formal program (such as Preparing Future Faculty, http://www.preparing-faculty.org/).

At the community level, we suggest investigating lessons learned by other, more established DBER fields to better understand strengths and weaknesses of existing programs and pathways. An initial inspection of the DBER literature reveals very little related to graduate education in other DBER fields. In a study of how early career scholars

entered physics education research (PER), Barthelemy et al. (2013) found that few scholars were aware of PER prior to starting graduate school, many perceived hostility toward PER as a subfield within physics, and it was noted that PER had higher participation of women (possibly linked to a more supportive culture) than disciplinary physics. Additionally, Kolopajlo (2014) provided guidance to graduate students seeking careers in academia in chemistry education. As such, a critical opportunity exists to collaborate with other DBER fields around graduate training models. The newly established DBER-Alliance (see Henderson et al., 2017; Shipley et al., this volume) will provide a potential avenue to make these connections and have these important conversations. We also suggest inviting speakers from other DBER fields to GER conferences and/or our departments and universities in order to facilitate these discussions.

Within the GER community, we recommend leveraging existing resources to further the discussion of graduate student preparation. We suggest that the newly established GER toolbox (http://nagt.org/nagt/geoedresearch/toolbox/index.html) include a new section that houses "GER-in-the-Field articles" highlighting GER-trained people who took various pathways and the training that they found most valuable for their positions. In a similar vein, the NAGT GER Division has created "Researchers in the Spotlight" in order to bring attention to faculty that have successfully navigated a GER career. In addition to the existing list of international graduate GER programs maintained by Julie Libarkin (2017), we also recommend developing a list of student dissertations and theses that have been published in GER. These would serve as examples for prospective students and as a community resource that illustrates the numbers of graduate students conducting GER research and topics of interest. The newly established GER toolbox also houses a section on "Getting your Geoscience Education Research Published" and includes a vast list of potential publication outlets, which could be helpful to GER graduate students as they consider publishing their research. We also recommend adding to the GER toolbox a list of grant opportunities available to GER graduate students, as well as proposal writing tips, in order to support their success in obtaining funding early in their careers. The combination of these existing and recommended support mechanisms at the community level would serve to assist graduate students in navigating their way through a variety of GER programs, from the newly formed to the more established graduate programs.

At the department and institutional levels, we see a need to continue to educate both the geoscience community and the science education community about GER. Both authors have found that disciplinary geoscience faculty have many misconceptions about what GER is and how GER is practiced (i.e., "You're the teaching person, right?"). We have also encountered bias against GER (and DBER broadly) from more established science education and educational psychology fields. We can educate our peers in geosciences and in education about what we do on both an organizational and an individual level. At the individual level, it is important for the GER researcher to frequently market their research to their colleagues less familiar with GER methods and approaches (Feig, 2013). At the organizational level, the Geoscience Education Research Division of NAGT held a Webinar in 2016 introducing disciplinary geoscience department heads and chairs to the benefits and challenges of having GER faculty (https://www.americangeosciences.org/workforce/webinars/benefits-and-challenges-having-geoscience-education-research-faculty-your). As a community, we need to maintain this momentum so that the contributions of GER faculty and their graduate students are known. While on the job market, GER candidates need to ask questions about how GER is viewed within the department and university in order to make an informed decision about the departmental and institutional culture. We also recommend that new GER faculty seek out a mentor, perhaps outside of geoscience education or outside of the home department entirely, who understands and values GER practice and can advocate on the new faculty member's behalf. Finally, GER faculty (and their students) need clear expectations (St. John, 2015). Dolan et al. (2017) described tenure and promotion considerations for DBER scholars. We encourage GER faculty and graduate students entering faculty positions to distribute this work to their administrators and use it as a means to start and continue conversations about the expectations for their position.

The recent growth in GER graduate programs reflects the growth of our field as a whole. We hope that this commentary sparks interest and conversation among the geoscience education community to consider what a GER graduate preparation program should encompass, and how GER graduates are prepared for a variety of career paths. Additionally, the community should take steps to face the challenges in hiring, retaining, and promoting success of both faculty and their graduate students in GER, in order to support and sustain active graduate GER programs.

Acknowledgments

We would like to thank the reviewers and editors for their valuable feedback in improving the manuscript during the review process. We would also like to thank the NSF for their support of the Geoscience Education Research workshop held at the Earth Educator's Rendezvous meetings in 2015–2017 and the participants who helped to inform aspects of this manuscript. Specifically, we would like to thank Leilani Arthurs, Eric Riggs, Steve Semken, and David McConnell for their insights, as well as the members of the "Navigating a Career in GER" working group.

REFERENCES

Barthelemy, R.S., Henderson, C., and Grunert, M.L. 2013. How do they get here? Paths into physics education research. *Physical Review Special Topics–Physics Education Research,* 9:020107–1-14.

Dolan, E.L., Elliott, S.L., Henderson, C., Curran-Everett, D., St. John, K., and Orti, P.A. 2017. Evaluating discipline-based education research for promotion and tenure. *Innovations in Higher Education*. DOI: 10.1007/s10755-017-9406-y

Feig, A. 2013. The allochthon of misfit toys. *Journal of Geoscience Education*, 61(3):306–317.

Henderson, C., Connolly, M., Dolan, E.L., Finkelstein, N., Franklin, S., Malcom, S., Rasmussen, C., Redd, K., and St. John, K. 2017. Towards the STEM DBER alliance: Why we need a discipline-based, STEM-education research community. *Journal of Geoscience Education*, 65(3):215–218.

Kober, N. 2014. Reaching students: What research says about effective instruction in undergraduate science and engineering. Washington, DC: National Academies Press.

Kolopajlo, L. 2014. What you need to start an academic career as a chemical educator. *In* Benvenuto, M.A., ed., *What You Need for*

the First Job, Besides the Ph.D. in Chemistry. American Chemical Society Symposium Series 1165:127–163. DOI: 10.1021/bk-2014-1165.ch012

Libarkin, J.L. 2017. Geocognition & geoscience education research programs: Alphabetical list. Available at https://geocognitionresearchlaboratory.wordpress.com/graduate-study/geocognition-geoscience-education-research-programs/ (accessed 21 June 2017).

National Association of Geoscience Teachers (NAGT). 2017a. Multiple paths into GER. Available at http://nagt.org/nagt/geoedresearch/toolbox/career/pathways.html (accessed 20 June 2017).

National Association of Geoscience Teachers (NAGT). 2017b. Geoscience education research. Available at http://nagt.org/nagt/geoedresearch/index.html (accessed 20 June 2017).

National Research Council (NRC) Committee on Prospering in the Global Economy of the 21st Century (U.S.), and Committee on Science, Engineering, and Public Policy (U.S.). 2007. Rising above the gathering storm: Energizing and employing America for a brighter economic future. Washington, DC: National Academies Press.

National Research Council (NRC). 2012. Discipline-based education research: Understanding and improving learning in undergraduate science and engineering. Washington, DC: National Academies Press.

National Science Board (NSB). 2015. Revisiting the STEM workforce: A companion to the science and engineering indicators 2014. Washington, DC: National Science Foundation.

President's Council of Advisors on Science and Technology (PCAST). 2012. Report to the president, engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. Washington, DC: Executive Office of the President, President's Council of Advisors on Science and Technology.

Seymour, E., and Hewitt, N. 1997. Talking about leaving: Why undergraduates leave the sciences. Boulder, CO: Westview.

Shipley, T.F., McConnell, D., McNeal, K.S., Petcovoc, H.L., and St. John, K.E. 2017. Transdisciplinary science education research and practice: Opportunities for GER in a developing STEM discipline-based education research alliance (DBER-A). *Journal of Geoscience Education*, 65(4): 354–362.

Snow, C.E., and Dibner, K.A., eds. 2016. Science literacy: Concepts, contexts, and consequences. Washington, DC: National Academies Press.

St. John, K. 2015. Being your own best advocate: Geoscience education researchers and the tenure track in traditional geoscience programs. *Journal of Geoscience Education*, 63(3):165–166.